

DEVELOPMENT OF INFLATABLE ANTENNA STRUCTURES

Michael LOU¹ and Houfei FANG¹

¹*Jet Propulsion Laboratory, California Institute of Technology
M/S 125/224, 4800 Oak Grove Drive, Pasadena, California, U.S.A.
E-mail: michael.c.lou@jpl.nasa.gov*

ABSTRACT: *Self-rigidizable spring-tape-reinforced (STR) booms were used to develop structural systems for large-aperture space inflatable radar antennas. The lightweight planar frames built with STR booms can be compactly stowed for launch, deployed by inflation pressure in space, and used to tension the RF membrane apertures of the antennas. Engineering models of a Ka-band reflectarray antenna and a L-band synthetic-aperture radar antenna were developed and have successfully demonstrated stowage and deployment, as well as RF performance. A design improvement was also being implemented to enhance long-term configuration stability and widen the application range of the STR booms.*

1. INTRODUCTION

Many space missions require in-space deployment of large flight systems. These flight systems include telescope reflectors, solar arrays, solar sails, sunshields, radar antennas and aerobrakes. In-space deployment has traditionally been performed by mechanically deployable structures that are heavy, bulky and of complicated designs. Recently, a newly emerging technology, space inflatable structures, has received much attention because these structures could potentially achieve order-of-magnitude mass and launch volume savings for large deployable systems. In particular, focused research efforts were initiated by NASA to apply space inflatable structures technology to the development of large space radars.

The basic building-block structural element of the inflatable antennas developed at JPL is a new type of self-rigidizable inflatable boom called the spring-tape-reinforced stretched aluminum laminate boom (or simply the STR boom). The STR boom has many advantages over other inflatable booms currently under development. This boom is of a very simple design and ultra-lightweight, has excellent packaging efficiency, uses space qualified materials, and requires very low inflation deployment pressure. More importantly, in-space rigidization of the STR boom does not require heat power or any chemical process and is, therefore, free of contamination and outgassing problems. The rigidity of a deployed STR boom is derived mainly from the reinforcing spring tape and interaction between the tapes and the stretched aluminum laminate boom wall. The processes of packing, deployment, and rigidization of a STR boom can be repeatedly performed without causing noticeable damage to the boom. This means that the flight unit of an inflatable structural system using STR booms can undergo packaging/deployment testing and its deployed configuration carefully measured in the ground to enhance mission reliability.

This paper will first give a brief review of baseline STR boom design and development. This will be followed by a discussion on the applications of STR booms to inflatable radar antennas. A

recently implemented design improvement that has significantly enhanced long-term space applicability of the STR boom will also be reported.

2. DEVELOPMENT OF THE STR BOOM

The design concept of the STR boom was derived from that of the stretched aluminum booms used in constructing the Next-Generation Space Telescope (NGST) inflatable sunshade. Previous study showed that as a space inflatable/rigidizable structure, the stretched aluminum laminate boom has many advantages over inflatable booms that use other space rigidization methods [1]. However, it was also observed that the aluminum laminate boom has two major shortcomings. Firstly, its load-carrying (buckling) capability is severely limited by certain design parameters such as material selection, wall thickness and the amount of pre-strain. Secondly, its failure mode (for a practical range of length to radius of gyration ratios, L/r) tends to be local buckling and is usually unpredictable. To overcome these shortcomings that have severely limited the applicability of the stretched aluminum boom, a new type of aluminum laminate booms called the spring-tape-reinforced boom (previously called the carpenter-tape-reinforced boom or CTR boom) was developed at JPL. This new boom not only have significantly improved buckling capability, but also preserved all major advantages of the non-reinforced aluminum laminate booms, including lightweight, reversibility for repeated ground testing and self-rigidizability. The baseline design of the STR boom includes the following features:

- The boom has a diameter of 7.62 cm (3 inches) and a nominal length of 5 meters.
- The boom wall is constructed with an aluminum laminate that consists of a 3-mil-thick 1145-0 aluminum sheet bonded and constrained by 1-mil-thick polyester films on both sides.
- Four longitudinal steel carpenter tapes (commercial grade) are attached to the inner surface of the boom wall. These tapes are equally spaced along the circumference.
- Machined aluminum end caps.

Figure 3 shows a cross-section of the STR aluminum laminate boom. Actual measurements of sample booms fabricated for buckling and dynamic tests indicated that the average boom weight is 0.18 kg per linear meter (excluding the end caps, which are approximately 0.25 kg each).

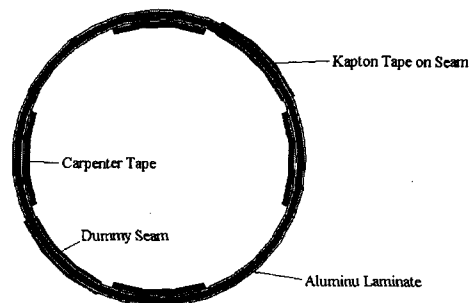


Figure 1. Cross-Section of a Baseline STR Aluminum Laminate Boom

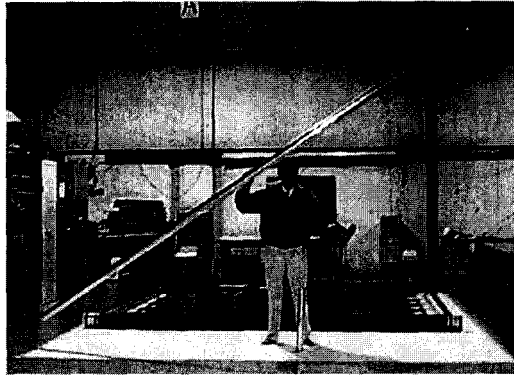


Figure 2. A Fully Deployed 5-Meter STR Boom

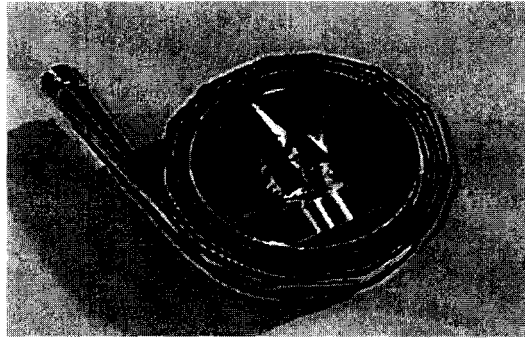


Figure 3. A 5-Meter STR Aluminum Laminate Boom Rolled Up on a 6.5-Inches-Diameter Mandrel

Finite-element model of the STR boom assembled and buckling and modal analyses were performed. An extensive test program, consisting have buckling, dynamic, packaging, and deployment tests, was also carried out mainly to verify the analysis results. These analytical and experimental studies, together with the results, have been reported in detail in [2]. A comparison of the dynamic analysis and test results is given in Table 1.

Table 1. Comparison of Dynamic Test and Analysis Results of the Baseline STR Boom

	1 st Frequency	2 nd Frequency	3 rd Frequency
Test	1.46 Hz	11.30 Hz	34.31 Hz
Analysis	1.47 Hz	11.54 Hz	34.21 Hz
Differences	0.7%	1.3%	0.3%

3. APPLICATION OF STR BOOMS TO SPACE RADAR ANTENNAS

In the past several years, the Jet Propulsion Laboratory (JPL) has been developing inflatable antennas for several classes of space radars, including the L-band synthetic-aperture radar (SAR) and the Ka-band reflectarray radar. Structural system concepts for these radar applications were generated and analyzed. Engineering models for these inflatable/rigidizable antennas were also designed, fabricated, assembled and tested.

Figure 4 illustrates the typical structural architecture used for all reflectarray antennas developed at JPL. This basic antenna support structure is a planar frame formed by four tubular

members. Two of the members, called the end bars, are rigid tubes made of a lightweight composite. The other two tubular members are STR booms that can be flattened and rolled up for stowage, deployed in space by inflation pressure, and are self-rigidized after the deployment is completed. The rest of the structural architecture consists of a membrane (or layered membranes) that perform the intended radio-frequency (RF) functions, cross bars, launch cover and restraint/release mechanisms, and a roll-up shell with two mandrels attached to its ends.

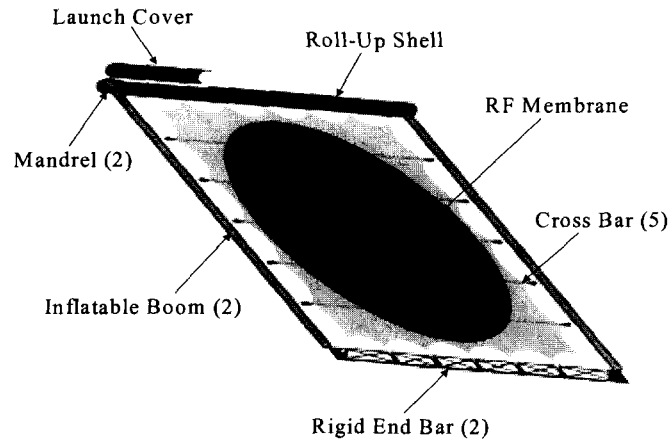


Figure 4. Typical Structural Architecture for Inflatable Radar Antennas

The RF membrane is attached to the four corners of the planar frame and tensioned by cables that put only compressions onto the STR booms. The cables tension is controlled by constant-force springs. Because the RF membrane must meet stringent flatness requirements, additional tensioning devices are needed. Firstly, the bending rigidity of the composite end bars is fully utilized to stretch, through catenaries, the RF membrane longitudinally. Secondly, rigid cross bars made of a lightweight composite material are added to the RF membrane. These cross bars, equipped with axial constant-force springs, will laterally stretch the membrane. The axial spring forces are balanced and will not impose any additional loads on the support planar frame.

Engineering models of inflatable radar antennas were recently fabricated. Figure 5 is a picture showing the one for a 3-meter-aperture Ka-band reflectarray. An end view of the same antenna in its stowed configuration is shown in Figure 6. Details of component design, fabrication, and assembly of this engineering model have been reported in [3 and 4].

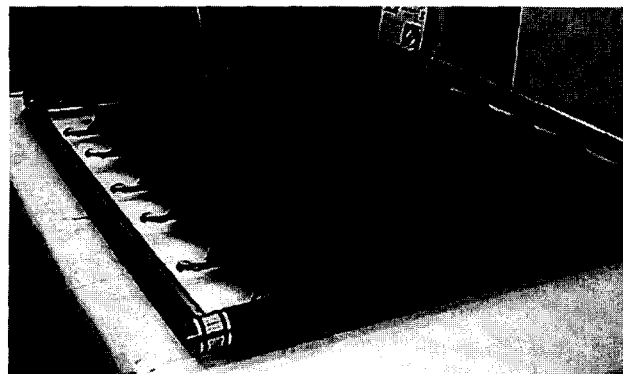


Figure 5. Engineering Model of the 3-M Ka-Band Inflatable Reflectarray Antenna

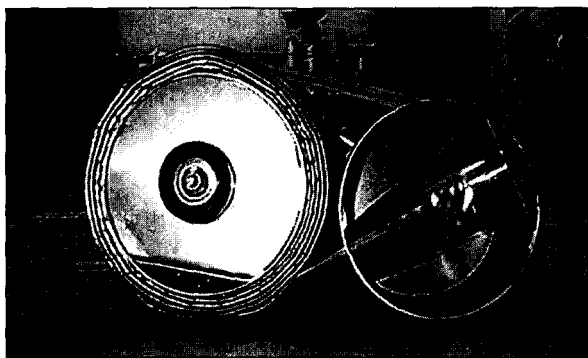


Figure 6. The 3-M Ka-Band Reflectarray Antenna in Stowed Configuration

A similar engineering model of basically the same structural architecture was fabricated for a L-band synthetic-aperture radar (SAR) antenna (see Figure 7). This engineering model represents one of the two wings of a synthetic-aperture radar with an aperture size of 3 meters by 10 meters.

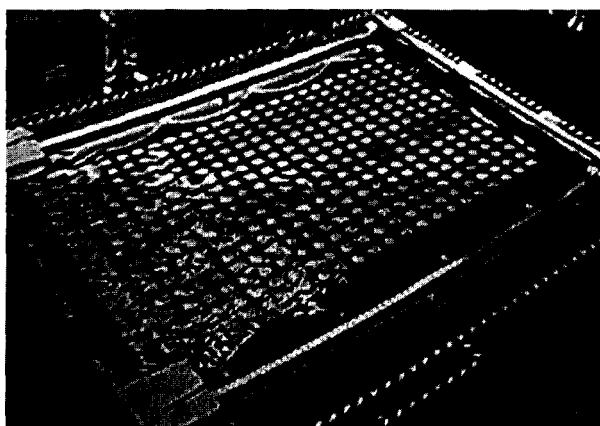


Figure 7. Engineering Model of the L-Band Inflatable SAR

Both of these engineering models are fully RF functional. They have also been subjected to repeated deployment and packaging tests with satisfactory results.

4. A RECENT IMPROVEMENT OF THE STR BOOM DESIGN

During the fabrication and testing of the baseline STR booms, it was observed that structural integrity of a deployed boom deteriorates over time. Results of an investigation into this observation discovered that after the internal pressure used to deploy the boom is vented out, the aluminum laminate skin of the boom wall will undergoes stress relaxation. When the stress relaxation reaches a certain degree, the boom's cross-section will change from a circular shape to a near-square shape that has the four longitudinal spring tapes at its four corners. It was experimentally proven that a boom with such a distorted cross section would have a substantially lower load-carrying capability. To remedy this deficiency of the baseline boom design, we decided to add circumferential rings to the boom such that long-term shape stability of its cross sections can be maintained. Figure 8 illustrates the concept of this design improvement.



Figure 8. STR Boom with Circumferential Rings

The following requirements were established for the design of the circumferential rings:

- 1) They must be able to be flattened such that the boom can be rolled up for stowage.
- 2) They must be able to autonomously assume and maintain a circular shape after the boom is deployed by inflation pressure.
- 3) They must have sufficient stiffness in the hoop direction of the boom to resist shape changes in cross-sections of the boom.
- 4) They must be lightweight and not require any complicated mechanisms for deployment.

Several ring design concepts, including a wide range of material selections, were developed, analyzed, and tested. The selected ring design consists of two semi-circular halves that are connected by semi-rigid hinges that enable the ring halves to be flattened for stowage. The ring halves are made of high-modulus spring steel strips and the hinges are formed by multiple layers of Kevla fabric. Figure 9 shows a partially flattened ring and Figure 10 shows the rings being installed onto the inner wall of a boom. Finite-element analyses of the modified STR boom design (i.e., the design with circumferential rings) were performed to optimize the ring thickness and width, as well as the distance between the rings. The analysis results indicated that a distance of 10 inches would give sufficient structural support to the boom in the hoop direction with an acceptable weight increase.



Figure 9. A Partially Flattened Circumferential Ring

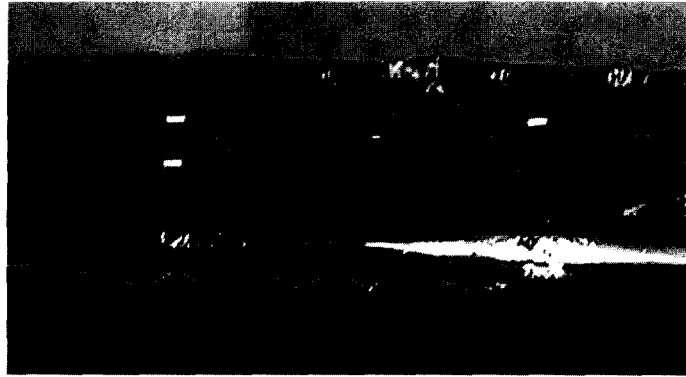


Figure 10. Circumferential Rings Being Installed Onto The Boom

Samples of the modified STR boom, also of 7.62 cm in diameter and 5 meters in length, were fabricated. Preliminary dynamic test results confirmed that although the modified booms are slightly heavier (average 1.4 kg each) than the baseline booms, their fundamental frequencies have noticeably increased (see Table 2). Figure 11 shows the set-up for testing the booms.

Table 2. Dynamic Test Results of the Modified STR Boom

Boom Sample#	1 st Frequency	2 nd Frequency	3 rd Frequency
1	1.63 Hz	11.25 Hz	32.38 Hz
2	1.63 Hz	11.00 Hz	31.56 Hz
3	1.63 Hz	11.19 Hz	32.44 Hz



Figure 11. Test Set-Up for Dynamic and Buckling Tests

5. CONCLUSION

The self-rigidizable STR booms have enabled successful development of large-aperture space inflatable radar antennas. A recently implemented design improvement of adding circumferential rings to the STR boom has greatly enhanced the boom's long-term configuration stability and structural integrity. The circumferentially reinforced boom can also carry higher lateral and bending loads and, thus, will widen its range of applications. Structural testing of sample booms and test/analysis correlation of the modified boom design is currently in progress.

6. ACKNOWLEDGEMENT

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration (NASA).

7. REFERENCES

- [1] M. C. Lou and V. A. Faria, "Development of Space Inflatable/Rigidizable Structures Technology," Presented at IUTAM-IASS Symposium on Deployable Structures: Theory and Applications, Cambridge, U.K., September 1998.
- [2] M. C. Lou, H. Fang, H., and L. Hsia, "A Combined Analytical and Experimental Study on Space Inflatable Booms," Proceedings of the 2000 IEEE Aerospace Conference. Big Sky, Montana, March 2000.
- [3] H. Fang, M. C. Lou, and L. Hsia, "An Inflatable/Self-Rigidizable Structure for the Reflectarray Antenna," Presented at 10th European Electromagnetic Structures Conference, Munich, Germany, October 2001.
- [4] H. Fang, M. C. Lou, J. Huang, L. Hsia, and G. Kerdanyan, "An Inflatable/Rigidizable Ka-Band Reflectarray Antenna", AIAA 2002-1706, Proceedings of the 43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference and Exhibit, Denver, Colorado, April 2002.